

The Electromagnetic Spectrum

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CHAPTER 1

The Electromagnetic Spectrum

Introduction

Imagine playing beach volleyball, like the young men in **Figure 1.1**. They may not realize it, but they are being bombarded by electromagnetic radiation as play in the sunlight. The only kinds of radiation they can detect are visible light, which allows them to see, and infrared light, which they feel as warmth on their skin. What other kinds of electromagnetic radiation are they being exposed to in sunlight? In this lesson, you'll find out.



FIGURE 1.1

Electromagnetic radiation from the sun reaches Earth across space. It strikes everything on Earth's surface, including these volleyball players.

What Is The Electromagnetic Spectrum?

Electromagnetic radiation occurs in waves of different wavelengths and frequencies. Infrared light and visible light make up just a small part of the full range of electromagnetic radiation, which is called the **electromagnetic spectrum**. The electromagnetic spectrum is summarized in the diagram in **Figure 1.2**.

- On the far left of the diagram are radio waves, which include microwaves. They have the longest wavelengths and lowest frequencies of all electromagnetic waves. They also have the least amount of energy.
- On the far right are X rays and gamma rays. They have the shortest wavelengths and highest frequencies of all electromagnetic waves. They also have the greatest amount of energy.
- Between these two extremes, wavelength, frequency, and energy change continuously from one side of the spectrum to the other. Waves in this middle section of the electromagnetic spectrum are commonly called light.

As you will read below, the properties of electromagnetic waves influence how the different waves behave and how they can be used.

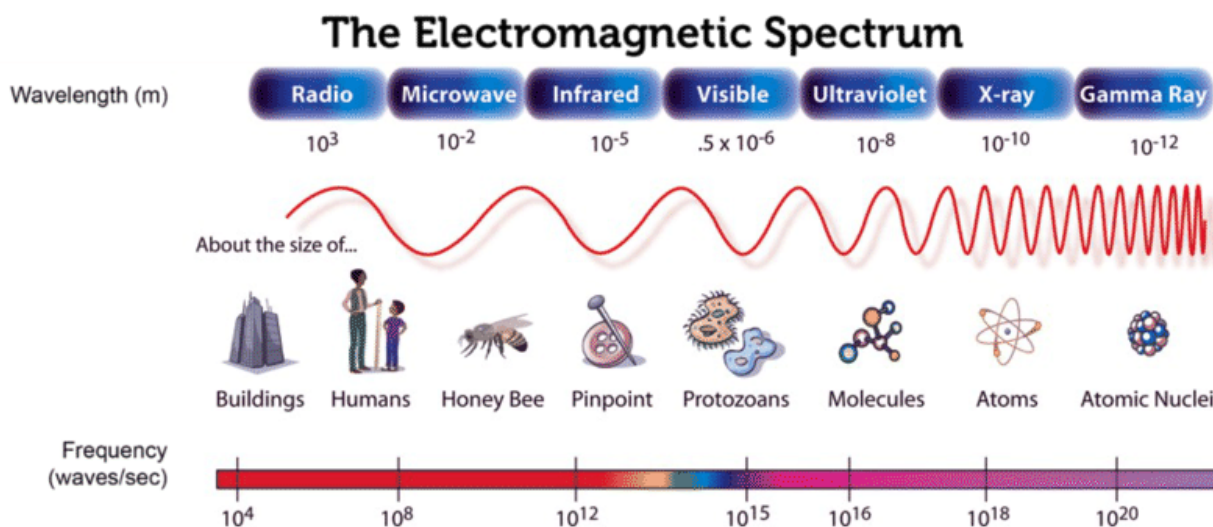
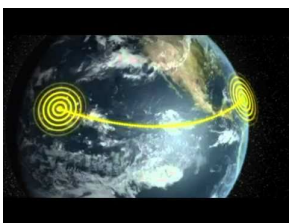


FIGURE 1.2

How do the wavelength and frequency of waves change across the electromagnetic spectrum?

Radio Waves

Radio waves are the broad range of electromagnetic waves with the longest wavelengths and lowest frequencies. In **Figure 1.2**, you can see that the wavelength of radio waves may be longer than a soccer field. With their low frequencies, radio waves have the least energy of electromagnetic waves, but they still are extremely useful. They are used for radio and television broadcasts, microwave ovens, cell phone transmissions, and radar. You can learn more about radio waves, including how they were discovered, at this URL: <http://www.youtube.com/watch?v=a17sF4P4C2TY> (3:58).



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AM and FM Radio

In radio broadcasts, sounds are encoded in radio waves that are sent out through the atmosphere from a radio tower. A receiver detects the radio waves and changes them back to sounds. You've probably listened to both AM and FM radio stations. How sounds are encoded in radio waves differs between AM and FM broadcasts.

- AM stands for amplitude modulation. In AM broadcasts, sound signals are encoded by changing the amplitude of radio waves. AM broadcasts use longer-wavelength radio waves than FM broadcasts. Because of their

longer wavelengths, AM radio waves reflect off a layer of the upper atmosphere called the ionosphere. You can see how this happens in **Figure 1.3**. This allows AM radio waves to reach radio receivers that are very far away from the radio tower.

- FM stands for frequency modulation. In FM broadcasts, sound signals are encoded by changing the frequency of radio waves. Frequency modulation allows FM waves to encode more information than does amplitude modulation, so FM broadcasts usually sound clearer than AM broadcasts. However, because of their shorter wavelength, FM waves do not reflect off the ionosphere. Instead, they pass right through it and out into space (see **Figure 1.3**). As a result, FM waves cannot reach very distant receivers.

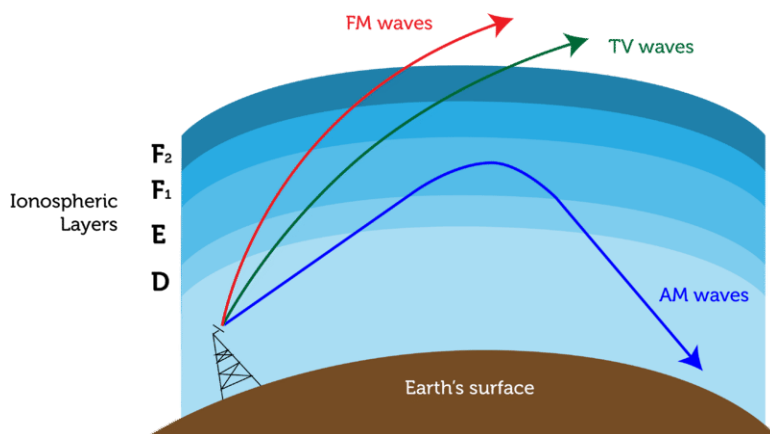


FIGURE 1.3

AM radio waves reflect off the ionosphere and travel back to Earth. Radio waves used for FM radio and television pass through the ionosphere and do not reflect back.

Television

Television broadcasts also use radio waves. Sounds are encoded with frequency modulation, and pictures are encoded with amplitude modulation. The encoded radio waves are broadcast from a TV tower like the one in **Figure 1.4**. When the waves are received by television sets, they are decoded and changed back to sounds and pictures.



FIGURE 1.4

This television tower broadcasts signals using radio waves.

Microwaves

The shortest wavelength, highest frequency radio waves are called **microwaves** (see **Figure 1.2**). Microwaves have more energy than other radio waves. That's why they are useful for heating food in microwave ovens. Microwaves have other important uses as well, including cell phone transmissions and **radar**, which is a device for determining the presence and location of an object by measuring the time for the echo of a radio wave to return from it and the

direction from which it returns. These uses are described in **Figure 1.5**. You can learn more about microwaves and their uses in the video at this URL: <http://www.youtube.com/watch?v=YgQQb1BVnu8> (3:23).



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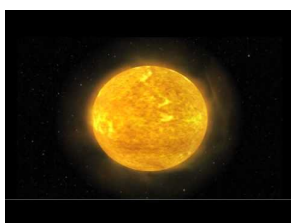
Light

Mid-wavelength electromagnetic waves are commonly called light. This range of electromagnetic waves has shorter wavelengths and higher frequencies than radio waves, but not as short and high as X rays and gamma rays. Light includes visible light, infrared light, and ultraviolet light. If you look back at **Figure 1.2**, you can see where these different types of light waves fall in the electromagnetic spectrum.

Visible Light

The only light that people can see is called **visible light**. It refers to a very narrow range of wavelengths in the electromagnetic spectrum that falls between infrared light and ultraviolet light. Within the visible range, we see light of different wavelengths as different colors of light, from red light, which has the longest wavelength, to violet light, which has the shortest wavelength. You can see the spectrum of colors of visible light in **Figure 1.6**. When all of the wavelengths are combined, as they are in sunlight, visible light appears white. You can learn more about visible light in the chapter "Visible Light" and at the URL below.

<http://www.youtube.com/watch?v=PMtC34pzKGc> (4:50)



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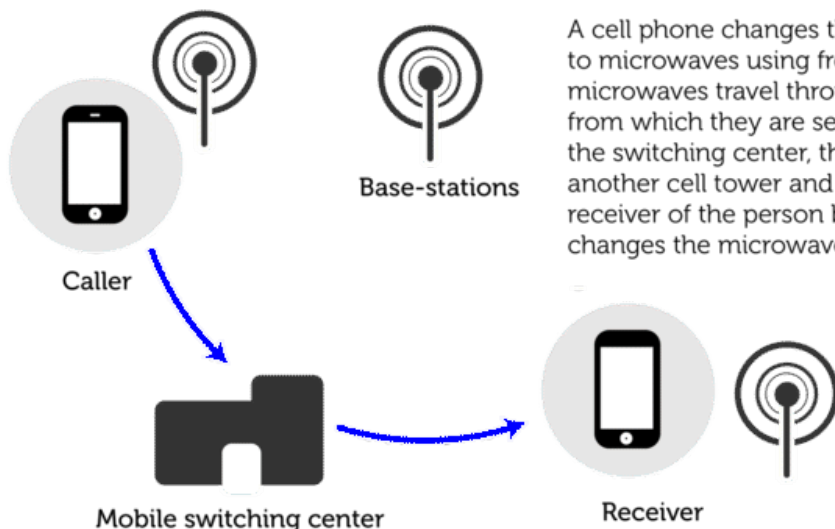
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Infrared Light

Light with the longest wavelengths is called **infrared light**. The term *infrared* means "below red." Infrared light is the range of light waves that have longer wavelengths than red light in the visible spectrum. You can't see infrared light waves, but you can feel them as heat on your skin. The sun gives off infrared light as do fires and living things. The picture of a cat that opened this chapter was made with a camera that detects infrared light waves and changes their energy to colored light in the visible range. Night vision goggles, which are used by law enforcement and the military, also detect infrared light waves. The goggles convert the invisible waves to visible images. For a deeper understanding of infrared light, watch the video at this URL: <http://www.youtube.com/watch?v=2-0q0XIQJ0> (6:46).

Cell Phones



A cell phone changes the sounds of the caller's voice to microwaves using frequency modulation. The microwaves travel through the air to a cell tower, from which they are sent to a switching center. From the switching center, the microwaves are sent to another cell tower and from the tower to the receiver of the person being called. The receiver changes the microwaves back to sounds.

Radar

Radar stands for radio detection and ranging. In police radar, a radar gun in a police car sends out short bursts of microwaves. The microwaves reflect back from oncoming cars. The time it takes for the microwaves to return to the radar gun is used to compute the speed of oncoming cars. Radar is also used for tracking storms, detecting air traffic, and other purposes.

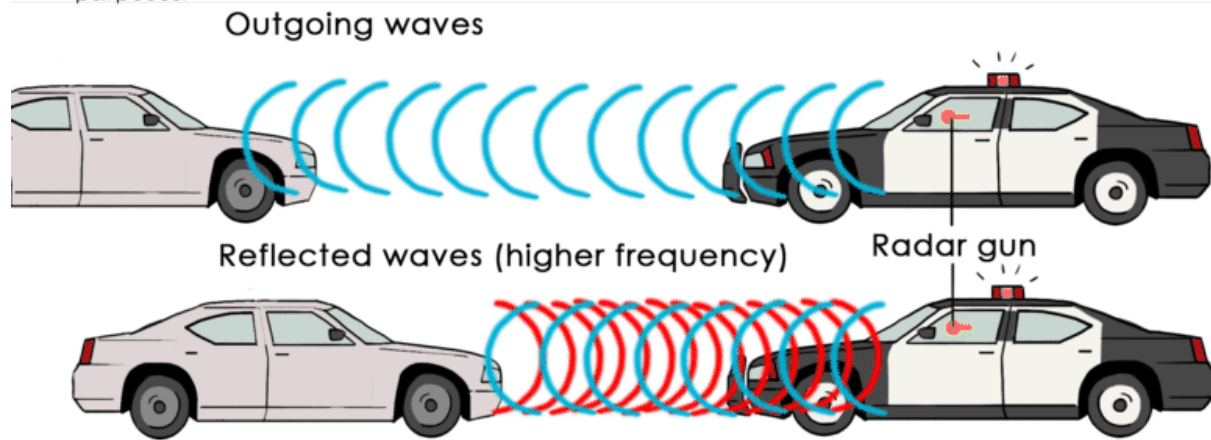


FIGURE 1.5

Microwaves are used for cell phones and radar.



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**FIGURE 1.6**

Red light (right) has the longest wavelength, and violet light (left) has the shortest wavelength.

Ultraviolet Light

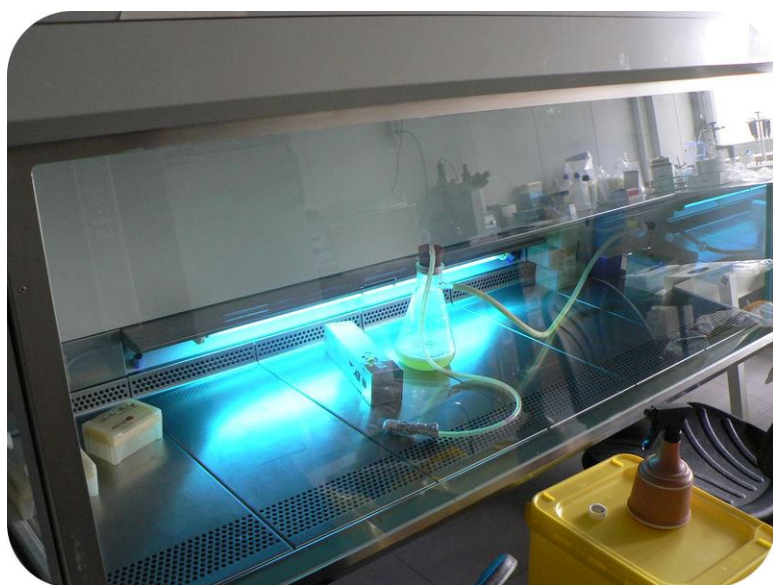
Light with wavelengths shorter than visible light is called **ultraviolet light**. The term *ultraviolet* means "above violet." Ultraviolet light is the range of light waves that have shorter wavelengths than violet light in the visible spectrum. Humans can't see ultraviolet light, but it is very useful nonetheless. It has higher-frequency waves than visible light, so it has more energy. It can be used to kill bacteria in food and to sterilize laboratory equipment (see **Figure 1.7**). The human skin also makes vitamin D when it is exposed to ultraviolet light. Vitamin D is needed for strong bones and teeth. You can learn more about ultraviolet light and its discovery at this URL: <http://www.youtube.com/watch?v=QW5zeVy8aE0> (3:40).



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URL: <http://www.ck12.org/flx/render/embeddedobject/1587>

**FIGURE 1.7**

This sterilizer for laboratory equipment uses ultraviolet light to kill bacteria.

Too much exposure to ultraviolet light can cause sunburn and skin cancer. You can protect your skin from ultraviolet light by wearing clothing that covers your skin and by applying sunscreen to any exposed areas. The SPF, or sun-protection factor, of sunscreen gives a rough idea of how long it protects the skin from sunburn (see **Figure 1.8**).

A sunscreen with a higher SPF protects the skin longer. You should use sunscreen with an SPF of at least 15 even on cloudy days, because ultraviolet light can travel through clouds. Sunscreen should be applied liberally and often. You can learn more about the effects of ultraviolet light on the skin at this URL: <http://www.youtube.com/watch?v=np-BBJyl-go> (5:59).



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FIGURE 1.8

If your skin normally burns in 10 minutes of sun exposure, using sunscreen with an SPF of 30 means that, ideally, your skin will burn only after 30 times 10 minutes, or 300 minutes, of sun exposure. How long does sunscreen with an SPF of 50 protect skin from sunburn?

X Rays and Gamma Rays

The shortest-wavelength, highest-frequency electromagnetic waves are X rays and gamma rays. These rays have so much energy that they can pass through many materials. This makes them potentially very harmful, but it also makes them useful for certain purposes.

X Rays

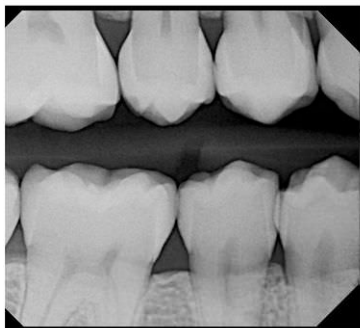
X rays are high-energy electromagnetic waves. They have enough energy to pass through soft tissues such as skin but not enough to pass through bones and teeth, which are very dense. The bright areas on the X ray film in **Figure 1.9** show where X rays were absorbed by the teeth. X rays are used not only for dental and medical purposes but also to screen luggage at airports (see **Figure 1.9**). Too much X ray exposure may cause cancer. If you've had dental X rays, you may have noticed that a heavy apron was placed over your body to protect it from stray X rays. The apron is made of lead, which X rays cannot pass through. You can learn about the discovery of X rays as well as other uses of X rays at this URL: <http://www.guardian.co.uk/science/blog/2010/oct/26/x-ray-visions-disease-forgeries> .

Gamma Rays

Gamma rays are the most energetic of all electromagnetic waves. They can pass through most materials, including bones and teeth. Nonetheless, even these waves are useful. For example, they can be used to treat cancer. A medical device sends gamma rays the site of the cancer, and the rays destroy the cancerous cells. If you want to learn more about gamma rays, watch the video at the URL below.

<http://www.youtube.com/watch?v=okyynBaSOtA> (2:45)

Dental X ray



Airport X ray

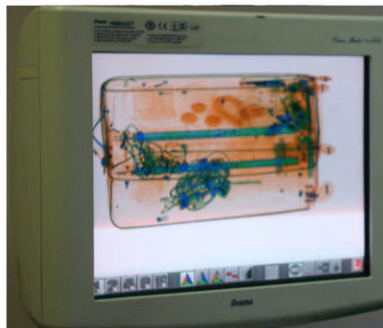


FIGURE 1.9

Two common uses of X rays are illustrated here.



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KQED: Seeing Cells in 3-D

Scientists in Berkeley have developed a powerful new microscope which uses X rays to scan a whole cell and in a matter of minutes, generate a 3D view of the cell and its genetic material. This groundbreaking tool is helping to advance research into the development of biofuels, the treatment of malaria and it may even help to more rapidly diagnose cancer. For more information on X ray microscopes, see <http://science.kqed.org/quest/video/x-ray-microscope-seeing-cells-in-3-d/> .



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Lesson Summary

- The electromagnetic spectrum is the full range of wavelengths and frequencies of electromagnetic radiation. Wavelength, frequency, and energy change continuously across the electromagnetic spectrum.
- Radio waves are the broad range of electromagnetic waves with the longest wavelengths and lowest frequencies. They are used for radio and television broadcasts, microwave ovens, cell phone transmissions, and radar.
- Mid-wavelength electromagnetic waves are called light. Light consists of visible, infrared, and ultraviolet light. Humans can see only visible light. Infrared light has longer wavelengths than visible light and is perceived as warmth. Ultraviolet light has shorter wavelengths than visible light and has enough energy to kill bacteria. It can also harm the skin.

- X rays and gamma rays are the electromagnetic waves with the shortest wavelengths and highest frequencies. X rays are used in medicine and dentistry and to screen luggage at airports. Gamma rays are used to kill cancer cells.

Lesson Review Questions

Recall

1. What is the electromagnetic spectrum?
2. Describe how wave frequency changes across the electromagnetic spectrum, from radio waves to gamma rays.
3. List three uses of radio waves.
4. How are X rays and gamma rays used in medicine?

Apply Concepts

5. Create a public service video warning people of the dangers of ultraviolet light. Include tips for protecting the skin from ultraviolet light.

Think Critically

6. Explain two ways that sounds can be encoded in electromagnetic waves.
7. Explain how radar works.
8. Compare and contrast infrared, visible, and ultraviolet light.

Points to Consider

This chapter introduces visible light. The chapter "Visible Light" discusses visible light in greater detail.

- In this lesson, you read that visible light consists of light of different colours. Do you know how visible light can be separated into its different colours? (*Hint*: How does a rainbow form?)
- In the next chapter, *Visible Light*, you'll read that visible light interacts with matter in certain characteristic ways. Based on your own experiences with visible light, how does it interact with matter? (*Hint*: What happens to visible light when it strikes a wall, window, or mirror?)

References

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